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Sustainability of biodiesel production as vehicular fuel in Indian perspective

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ABSTRACT

Biodiesel production offers promising opportunities to create additional alternate sources of energy. Since India is deficient in edible oils, the non-edible oil like jatropha, neem, karanja, mahua, simarouba etc., could be the desirable source for India for production of bio-diesel. This brief presents the current status, discusses the future prospects and examines the critical constraints and impediments in India to the path of development of biodiesel program. It also offers suggestions and alternative policy options so as to enable the program to achieve its objectives. The effects of biodiesel on engine performances i.e. brake power, brake thermal efficiency, specific fuel consumption and substantial reduction in particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO) and oxide of nitrogen (NO_x) were also reviewed.

Contents

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1. Introduction

Biofuels are globally considered sustainable and eco-friendly source of energy to enhance national energy security and decrease dependence on imported fossil fuels. Main user of diesel fuel in India is the agriculture sector next to transport sector. The demand for diesel fuel exceeds its availability resulting in its scarcity and is projected to increase at an annual rate of 5.8% [1]. Biodiesel demand and over-capacity in Europe, US and Asia are driving investment in the global trade of alternative feedstocks (Fig. 1).

1.1. Energy scenario of India

With the growing population of petroleum fuel, India is the fifth largest primary energy consumer (per international energy annual) and the fourth largest petroleum consumer in the world [2]. India produced around 1073 million litres of ethanol in 2009 (USDA 2010) of which around 100 million litres was blended with petrol to be used in automobiles as fuel. Now the country becomes world's 7th largest ethanol producer, with an annual production of 200 million litres of ethanol [3,4]. The per capita energy consumption of India was 439 KGOE in 2003, which was much lower than in developed countries (i.e. 1090 in China, 7835 in USA) but also than the global average of 1,688 KGOE [5]. In 2008–09 with the limited reserves, India's indigenous production was around 33.51 million tons and consumption was around 161.7 million tonnes. India does not have the ability to meet the country's growing demand for energy from indigenous sources even in the short term. As a result, the country is increasingly becoming dependent on imported crude oil. In the past few years India has been a net importer of liquid fuels and the volume and value of these imports have risen (Fig. 2). The import of crude oil has risen from 57.8 million tonnes. ($9.21 billion) in 1999–2000 to approximately 140.4 million tonnes. ($75.6 billion) in 2009–10, accounting for about 81% of total oil consumption in the country [6]. With the country entering a more energy intensive phase of its development, demand for transportation and consequently liquid fuels will dramatically rise in the future. Nowadays, all the tractors and other heavy duty vehicles are powered by compression ignition (CI) engines using diesel fuel. The vehicular pollution is contributing about 70% to the total air pollution and estimated to have increased eight times over the last two decades. India's total carbon emissions are increasing at an estimated 3.2% per annum, against 3.9% in China and 1.3% in the United States [3,5].

Out of various possible new alternative sources of energy, biodiesel has potential as an alternative energy source. However, biodiesel alone will not solve our dependence on foreign oil within any practical time frame. Biodiesel is a viable substitute for petroleum-based diesel fuel. Biodiesel operates in compression ignition (diesel) engine, which essentially requires very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. Moreover, a renewable fuel will help reduce India's carbon dioxide emissions.

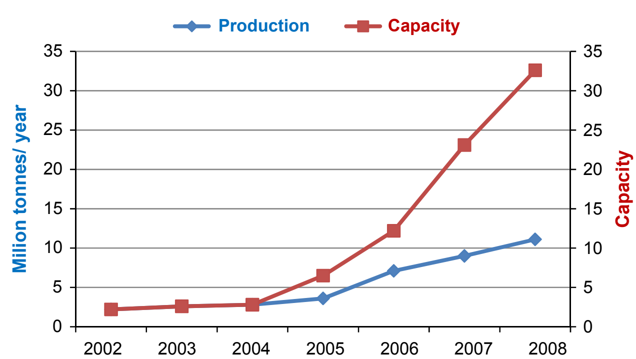

Fig. 1. World biodiesel production and capacity.

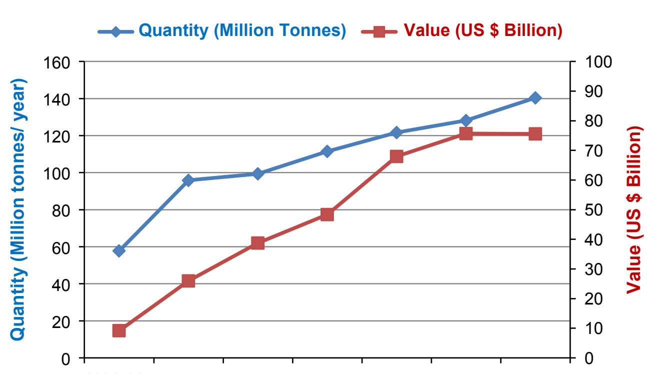

Fig. 2. Crude Oil Imports by India, 1999–2009.

1.2. National policies on biofuels

The biofuels industry in India is basically controlled by the government agencies to encourage investment in this field. In the recent decade, the Government has formulated certain policies and promoted the production and consumption of biofuel. In 2003, the Government of India launched National Biofuel Mission with a view to explore the potential of biofuels as a cleaner source of energy and to partially offset the growing burden of crude oil import bills. Under the Ethanol Blended Petrol Programme (EBPP) the Government made it mandatory to blend petrol with 5% of ethanol across the country except Jammu and Kashmir, north-eastern states and Island territories [7]. However, this figure is quite low as compared to those of other countries such as Brazil, USA, China and Indonesia. This policy envisages a target of complete blending 10% by 2016–17 and then gradually raise it to 20% after 2017 [8,9]. In 2009 the 'National Policy on Biofuels' by the Ministry of New and Renewable Energy (MNRE) launched to mainstream the biofuels, particularly in the transportation and energy sectors. This stimulates rural development and generates employment opportunities, as well as aspires to reap environmental and economic benefits arising out of their large-

scale use. Though 85 plants in 22 countries are already producing biodiesel, the Government has commissioned two commercial projects in Andhra Pradesh and Maharashtra to test the efficiency of biodiesel in diesel-run vehicles. The Petroleum Conservation Research Association (PCRA) has also set up a Biodiesel Credit Bank to pursue the different activities in the country for propagating, promoting and developing biofuels.

The Government of India has identified 400,000 square kilometers (98 million acres) of waste land where Jatropha can be grown, hoping to replace 20% of India's diesel consumption by 2017. With the recent government drive to produce biodiesel from TBO, many state governments have given very high priority to plantations of Jatropha for biodiesel production [10]. It is estimated that the existing potential of tree-borne oilseeds in the country is 3–3.5 million tonnes but only 0.5–0.69 million tonnes are being collected [11].

1.3. SWOT analysis of biofuel programme in India

As presented in Table 1 the SWOT analysis of biofuels programme is described as follows.

1.3.1. Strength and economic viability of biodiesel

India has vast tracts of degraded lands, mostly in areas with adverse agro climatic conditions, where hardy tree borne oil seeds species like jatropha, neem, karanja, mahua and simarouba can be grown easily. In different states of India, the total area of jatropha (748,782 ha), neem (617,500 ha), karanja (36,000 ha), mahua (62,500 ha) and simaroubain (1885 ha) is presented in Table 2 [9,12,13]. Wasteland development would require an investment of about $ 200 crore per year thus making a significant and important contribution to the goal of Energy Independence for the next 20 years.

Table 1
SWOT analysis of Biofuels in India.

Strengths	Weaknesses	Opportunities	Threats
• Vast tracts of degraded lands • Energy security of the country • Less GHG emissions, environment friendly • Higher Cetane number and better lubricating effect for biodiesel	• Lack of experience in plantation development and management • Higher cost of extraction and transesterification due to low capacity utilization • Less market value • Long gestation period	• Cost effective alternate fuel • Increasing agricultural, chemical and petroleum industry • Generation employment • Less dependency on depleting fossil fuels • Eco friendly fuel	• The discovery of huge gas reserves in India may push biofuels on the backfoot • Cost effectiveness of Biofuels

Table 2
Area (ha) under major tree born oilseeds for production of biodiesel in India.

S.No.	Name of State	Jatropha (*Jatropha curcas*)	Neem (*Azadirechta indica*)	Karanja (*Pongamia pinnata*)	Mahua (*Mashuca indica*)	Simarouba (*Simarouba glauca*)
1.	Andhra Pradesh	1,500	59,856	7,009	5,620	–
2.	Assam	100	3,101	712	3	–
3.	Arunachal Pradesh	235	12	28	34	–
4.	Bihar	200	7,979	180	1301	–
5.	Chattisgarh	304,152	14,657	1,895	7,793	–
6.	Dadra Nagar Haveli	45	232	53	245	–
7.	Gujarat	1,300	42,794	718	1,554	10
8.	Delhi	–	3,333	168	–	–
9.	Haryana	1,405	12,534	553	55	–
10.	Himachal Pradesh	489	845	843	10	–
11.	Jammu & Kashmir	9	212	5	–	–
12.	Jharkhand	800	9,940	1,416	2,570	–
13.	Karnataka	670	41,666	3,580	3,037	1,860
14.	Kerala	50	16,457	685	1,047	–
15.	Madhya Pradesh	374,648	50,066	4,235	15,884	–
16.	Maharashtra	2,360	59,903	2,201	5,341	15
17.	Manipur	450	668	19	–	–
18.	Meghalaya	446	216	347	3	–
19.	Mizoram	380	–	–	–	–
20.	Nagaland	490	–	–	–	–
21.	Orissa	–	13,324	1,506	5,367	–
22.	Puduchery	–	17,207	1,830	37	–
23.	Punjab	300	12,836	319	37	–
24.	Rajasthan	10,554	60,768	595	3,257	–
25.	Sikkim	150	51	–	3	–
26.	Tamilnadu	900	96,413	4,176	1324	–
27.	Tripura	150	440.21	3.93	–	–
28.	Uttar Pradesh	12,000	70,193	1,929	6,482	–
29.	Uttarakhand	13,500	2,527	513	838	–
30.	West Bengal	21,500	19,125	481	658	–
	Total	**748,782**	**617,359**	**36,000**	**62,500**	**1,885**

Refs. [9,12,13].

Biofuels are an attractive renewable alternative to conventional fossil fuels. Due to its renewable nature biofuels do not accumulate any carbon dioxide in the environment thus offering opportunities for trading of carbon credits. In other words they are carbon neutral, low on sulfur-based pollutants, and promote energy independence. Its advantages are higher cetane number, molecular weight, viscosity, lubricity, density and flash point than diesel fuel, cleaner emissions (except for NO_x), reduced global warming, and enhanced rural development. Biodiesel has an energy content that is about 12% less than petroleum-based diesel fuel on a mass basis.

1.3.2. Weakness

However, although the potentials have already been recognized years ago, not much actual biodiesel production has taken place so far. No exact numbers are available on the amount of biodiesel produced, but it is probably marginal. The low levels of production are mainly due to two reasons. First, private farmers and entrepreneurs are hesitant to take up biodiesel production because the activity, with the exception of some niche markets, is not yet economically viable. Although plantation is taking off in several Indian states, it still depends on subsidized programmes. Second, the long gestation period of at least three years (in the case of Jatropha) is another reason for the rather slow development of the biodiesel sector in India.

1.3.3. Opportunities and potential of biodiesel in India

Once indigenous production of biodiesel starts in India, it would provide a cleaner and cheaper alternative to petroleum-based fuels. Thus, biodiesel could provide a direction to India's search for a cost effective alternative fuel in the volatile world market faced with fast-depleting reserves of non-renewable petroleum-based fuels. This technology will provide new horizons to the small and middle scale industries in India because bio-diesel would be produced in the local industries. This renewable technology is totally based on the non-edible oilseeds like Jatropha, neem and karanja, which are known to grow in Indian subcontinent. Hence, it will help the agriculture industry, chemical industry, petroleum industry, etc. in terms of employment generation. Addition of bio-diesel to petro-diesel will bring down the sulfur level and enhance the fuel quality in terms of low aromatics and higher lubricity. Petroleum industry will be able to market fuel that is safe, eco-friendly and requires no extra infrastructure.

As an estimate, Indian Railways can produce bio-diesel meeting 10–12% of their total diesel requirement and replace that much amount of diesel. Railways consume about 2 MT of diesel per year (5% of the total Indian production). The main interest of Railways in bio-diesel programme is leading to lesser wear and tear and also desiring a low sulfur and better lubricity fuel being provided by bio-diesel. Therefore, replacing petro-diesel with bio-diesel has inherent advantages both for fuel marketing companies and for captive users. Indian Railway planted 75 lakh Jatropha saplings in Railway land which is expected to give yields from the current year onwards.

1.3.4. Threats

The discovery of huge gas reserves in India may push biofuels on the backfoot. The production of methyl esters from edible oils is currently much more expensive than hydrocarbon-based diesel fuels due to the relatively high costs of plant oils.

2. Material and methods

This section describes some general aspects of the biodiesel value chain in India. This will help to better understand and assess the developmental impacts of biodiesel production and consumption.

2.1. Production of biodiesel

2.1.1. Processing

Once the fruits have been harvested, the first step in production is extracting the oil. Only the seed of the fruit contains oil, so it is necessary first to separate the seed from the fruit hull. The seed itself also consists of a shell and a kernel. Before the oil is expelled, it is more efficient to remove the seed shell from the kernel in order to improve the extracted neat vegetable oil. If this is not done, sediments of the shell will remain in the Straight vegetable oil.

2.1.2. Transesterification

The second step in production of biodiesel is Transesterification, which is used to degum, dewax and remove triglycerides from the vegetable oils. It is the process of using an alcohol (e.g. methanol, ethanol or butanol), in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to break the molecule of the raw renewable oil chemically into methyl or ethyl esters of the renewable oil, with glycerol as a by-product [14]. This transesterified vegetable oil is termed as biodiesel. Biodiesel (Greek, bio, life+diesel from Rudolf Diesel) refers to a diesel-equivalent, processed fuel derived from biological sources.

2.2. Blends of biodiesel

Biodiesel can be blended with petroleum diesel in many proportion, i.e. B2, B5, B10, B20 and B100. B2 contains 2% biodiesel in 98% petroleum diesel, B5 contains 5% biodiesel in 95% petroleum diesel and B10 contains 10% biodiesel in 90% petroleum diesel. Similarly, B20 contains 20% biodiesel and B100 contains 100% biodiesel [15]. Blends of 20% biodiesel and lower can be used in diesel engine with no or only minor modifications, although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends. The B6–B20 blends are covered by the American Society for Testing and Materials (ASTM D7467) specification [1]. For a short term running and for small engines, the neat vegetable oils can be used only; however for long-term use and for heavy engines, blends of diesel and vegetable oils were recommended [16].

3. Results and discussion

3.1. Biofuel plants in India

There are major five species with economic potential for biodiesel production, including Jatropha (*Jatropha curcas*), Neem (*Azadirachta indica*), Karanja (*Pongamia pinnata*), Mahua (*Madhuca indica*) and Simarouba (*Simarouba glauca*). The production of these plant oils is presented in Table 3. The effects of biodiesel on engine performances i.e. brake power, brake thermal efficiency, specific fuel consumption were described as under.

3.2. Jatropha (Jatropha curcas)

Jatropha has been identified as most potential plant for biodiesel due to its advantages over other plant species. Among the various tree-borne non-edible oilseeds, *Jatropha curcas* is getting priority over others due to several advantages. The fuel properties of Jatropha are very nearer to that of conventional diesel fuel (Table 4). *Jatropha curcas* oil as a substitute for CI engine gives the lower brake thermal efficiency and higher specific fuel

Table 3
Production of oil-bearing tree species in India.

Physical Characteristics	Jathropha (*Jatropha curcas*)	Neem (*Azadirechta indica*)	Karanja (*Pongamia pinnata*)	Mahua (*Mashuca indica*)	Simarouba (*Simarouba glauca*)
Height, m	3–4	15–20	15–25	21–23	15
Climate	Arid, semi-arid and tropical areas with rainfall between 1000 and 1500 mm; mixed hot and humid climate preferred; cannot withstand frost	Grows under subarid to sub-humid conditions with 400–1200 mm annual rainfall	Grows almost throughout India up to altitude of 1200 m. Requires of 500- 2500 mm annual rainfall; cannot withstand frost	–	Grows almost throughout India up to altitude of 1000 m. Requires 700- 4000mm
Soil	Hardy plant growing also on stony, gravely or shallow and calcareous soils with low fertility, well drained soils required	Wide varieties of soils including clayey, saline and alkaline soils, with pH up to 8.5. Deep and well-drained black cotton soil preferred	Tolerate to salinity, alkaline and water logging soils	–	Wide varieties of drained soils with pH from 5.5 to 8.0. Loamy and red laterites are preferred
Gestation Period (years)	2–3	5–6	4–7	8–15	6–8, (3–4) when grafted
Oil content per seed (in %)	28–35	45	27–39	35–40	50–60 plus 20–32% oil in the nutlet
Yield per tree (kg)	1–2.5	15	20–25	20–40	15
Density of Plant/ha	1500	400	500	200	500
Source: Refs.	[22,51]	[31,52]	[53,54]	[39]	[42,43]

Table 4
Fuel properties of selected plant oil and their esters.

S. No.	Fuels and their esters	Calorific value (MJ/Kg)	Density (g/ml)	Flash point (°C)	Cetane no.	Iodine value	Viscosity (mm^2/s, 40°C)	References
1.	Diesel	42.0–47.4	0.820–0.849	44.0–74.0	45–55	220	3.9–6.8	[29,30,37,38,49]
2.	Jatropha oil (*Jatropha curcas*)	38.2–49.8	0.900–0.940	180–280	33.7–51.0	93–106	24.5–52.76	[11,20,21,23,55]
3.	Jatropha oil methyl Esters	37.2–40.9	0.862–0.890	180–280	43–59	101.7	3.0–8.16	[11,21,23,49,55]
4.	Neem oil (*Azadirechta indica*)	33.4–41.6	0.912–0.965	34–285	51	65–80.8	20.5–48.2	[29–31,56]
5.	Neem oil methyl ester	39.1–40.2	0.780–0.942	245	48–53	35.8	3.2–10.7	[29–31,56]
6.	Karanja (*Pongamia pinnata*)	45.0–67.0	0.870–0.928	198–263	42–67	87	27.8–56.0	[53–55]
7.	Karanja oil methyl ester	36.0–42.1	0.865–0.898	110–187	36–61	80–90.7	3.8–9.6	[38,53,55,57]
8.	Mahua oil (*Mashuca indica*)	34.3–38.9	0.861–0.960	212–276	43.5	65	24.6–44.3	[39,56,34,35]
9.	Mahua methyl ester	36.7–43.0	0.828–0.872	56–208	47–51	60	2.7–10.4	[34–36,41]
10.	Simarouba (*Simarouba glauca*)	37.6	0.860–0.906	138–242	–	50–54	4.3–17.3	[42–44]

consumption compared to diesel fuel operation. Moreover, HC, CO and NO_x emissions are higher and smoke level is lower than those of dual fuel operation with diesel [17–22]. The short term experiments to determine diesel engine performance on jatropha oil esters found that it produced 81% of the maximum power, 86% of the maximum torque and 115% of the specific fuel consumption as compared to the standard diesel fuel [17]. The brake thermal efficiency (BTE) decreases and brake specific fuel consumption (BSFC) increases with the increase in percentage of jatropha biodiesel blends. An increase in BSFC for B20, B50, B100 of jatropha blends was in the range of 2.86%, 6.0%, 12.37% when tested in a 3-cylinder WC tractor engine at rated speed [18,19]. A significant improvement in performance, emissions and combustion parameters can be obtained by properly optimizing the compression ratio, injector opening pressure, injection timing, injection rate and enhancing the swirl level when a diesel engine is to be operated with neat jatropha oil and its blends [20]. The increase in compression ratio leads to increase in emission of HC and exhaust temperature, whereas smoke and CO emission reduce [21]. NO_x emissions remained unaffected at higher injection pressure. Decreases in smoke for B20, B50 and B100 are 28.57%, 40.9%, 64.28% observed at the rated speed, respectively. The PM emissions of biodiesels from jatropha methyl ester were higher than the reference diesel however it decreases remarkably with increasing biodiesel content in blends. At 80% load on diesel engine, the NOx and CO emissions of 0.115% and 970 ppm were reported using jatropha blends as compared to diesel 0.1125% and 1080 ppm respectively [22,23]. The 10% increase in HC emissions was obtained for methyl ester of jatropha oil with regard to diesel [24]. This increasing trend of HC emissions may be due to relatively poor atomization and lower volatility of biodiesels. The jatropha oil blends B50 can be used in the engine without any hardware modification in the engine without any undesirable combustion features such as knocking.

3.3. Neem oil (Azadirechta indica)

Neem has been used in India from time immemorial for protecting food and food products from the infestation of pests, insects and other diseases. Neem is grown from the southern tip of kerala to the Himalyan hills spreading from tropical to subtropical and semi-arid to wet tropical regions. Various aspects of engine performances using B20 were studied by [25] on a single-cylinder DI diesel engine at different injection pressures and they obtained that the BSFC was slightly higher at all loads for B20 compared with pure diesel but the same values of brake specific energy consumption (BSEC) indicated that the efficiency at which energy was utilized was the same at an injection pressure of 15.7 MPa. Same trend of BSFC was reported by [26,27].

Higher brake thermal efficiency (BTE) of biodiesel blends than the standard diesel was found by [27]; however, slight reduction in BTE was reported by [28]. The initial increase in BTE may be

attributed to the complete and high combustion of fuel, but once the load reached at full load level, the time taken for complete combustion of fuel was decreased; hence a slight drop in BTE was observed. Similar findings were also reported by [29]. The reduction in BTE with biodiesel blends was due to higher viscosity, poor spray characteristics and lower calorific value. The higher viscosity leads to decreased atomization, fuel vaporization and combustion [30]. The difference of BTE between biodiesel and pure diesel tended to increase with the increase of fuel injection pressure. A significant effect of injection pressure on oxide of nitrogen (NO_x) emissions at full load is reported by [25]. They also reported that carbon monoxide (CO) emissions decreased as load increased, but at heavy load or full load it increases slightly. At B30 blends of neem oil more smoke particulates and fouling of lubricants was reported by [26]. The combustion starts earlier for higher biodiesel blends however start of combustion was slightly delayed for lower blends of biodiesel when compared with standard diesel [27]. The optimum conditions to achieve maximum yield of biodiesel were investigated by [31] at different temperatures and with different molar ratios of neem oil and methanol. The temperature increases yield of methyl ester at 55°C and a molar ratio of 1:12 was found to be beneficial.

3.4. Karanja oil (*Pongamia pinnata*)

Karanja is believed to be originated in India and distributed throughout the country from the Ravi river eastward in the hills of south India up to elevation of about 1200 m. It is widely grown from tropical dry to subtropical dry forest life zones [19]. The investigations were carried out by various researchers in studying the fuel properties of karanja methyl ester and its blend with diesel oil on the performance and emission characteristics of internal combustion engine (IC) engine. Most of the researchers [32–37] observed the reduction in exhaust emissions together with increase in torque, brake power, BTE and reduction in BSFC made the blends of karanja esterified oil a suitable biofuel. The required percentage of blend of karanja oil with diesel ensure the optimum performance and low-emission characteristics [32]. Lower BTE of karanja biodiesel as compared to diesel was observed by [33], whereas higher BTE was found by [34] and [35] with B20 blend of karanja oil methyl ester at an injection pressure of 20 MPa. This may be due to better atomization and mixing of fuel with air, which results in better combustion of fuel. However [36] reported that using B50 blends BTE is 21.69% poorer than diesel. An increase in BSFC for B20, B50 and B100 esters with diesel on a 3-cylinder WC tractor engine was reported in the range of 2.68%, 5.84% and 13.31% with respect to diesel at rated speed [19]. HC, CO and NO emissions from karanja oil methyl ester was slightly higher as compared with conventional diesel fuel. HC emission of diesel at maximum load was 85 ppm, while that of biodiesel was 120 ppm due to poor mixing with air. CO emission of karnaja biodiesel at maximum load was reported to be 0.21% as compared to 0.18% of standard diesel fuel [33]. A higher reduction in CO emissions was shown by [35], who observed that the reducing range was 73–94% using karanja blends from B20–B100 as compared to diesel however lower emissions are reported by [36] for blends as compared to biodiesel. It was also reported that NOx emission in the case of biodiesel is approximately 12% higher than that of diesel fuel, which may be due to the higher temperature of biodiesel combustion chamber. A reduction in smoke was observed 28.96%, 44.15% and 68.83% with B20, B50 and B100 esters with respect to diesel at a rated speed [19]. Higher emissions from karanja ethyl ester than the methyl esters were reported by [37,38]. This is due to the presence of more oxygen for methyl esters.

3.5. Mahua oil (*Madhuca indica*)

Mahua is one of the forest based tree-borne non-edible oils with large production potential of about 60 million tonnes per annum in India [39]. The kernel of the mahua fruit contains about 50% oil. The oil yield is 34–37% by small expeller. The performance and exhaust emission of mahua oil blends in a four stroke diesel engine and its comparison with diesel fuel are given by [40]. All mahua oil blends (10, 20 and 30%) have almost similar thermal efficiency and are very close to the thermal efficiency of diesel fuel. The smoke density is higher for mahua oil blends compared to diesel at lower loads. Smoke density increased with proportion of mahua oil in diesel [41]. The differences of brake thermal efficiencies between diesel fuel and neat mahua oil were not significant at engine settings of compression ratio of 20:1 and injection timing of 40° TDC. The mean brake thermal efficiency of neat biodiesel of mahua oil at full load conditions was about 10.1% lower than that of diesel fuel while at lower loads, the variation was as high as 17.1% [41].

3.6. Simarouba (*Simarouba glauca*)

Simarouba is an important tree species growing in the forests of Central and South America and introduced in India in the 1960s [42]. Simarouba oil is edible, but its consumption for cooking is not habitual

Table 5
Problems and causes of vegetable oil run diesel engines.

S. No.	Problems	Causes of problem	References
1.	Carbon deposits on piston, piston rings, valves, engine head and injector tips	High viscosity of vegetable oil, incomplete combustion, poor combustion in partial load	[61,62]
2.	Fuel Filter plugging, injector coking, nozzle blocking	Polymerization products, impurities, free glycerin, FAME process chemicals (K, Na, detergents etc.)	[63,64]
3.	Failure of engine lubricating oil	Collection of polyunsaturated vegetable oil, blow-by in crankcase to the point where polymerization.	[61,64]
4.	Cold weather starting	High viscosity, low cetane and low flash point of vegetable oils	[50,65,66]
5.	Heavy gum and wax formation, deposition on piston, piston rings, injectors and cylinder wall	High viscosity, oxidation	[67]
6.	Corrosion of high pressure injecting pump, injector nozzles, supply or feed pumps, high pressure pipes	Free water, free FAME, corrosive acids (formic and acetic), free methanol, NaOH or KOH particles in fuel, high viscosity at low temperature, iodine value, total acid number, etc.	[68]
7.	Fuel delivery problems, poor nozzle spray atomization	Higher viscosity at low temperature	[68]
8.	Elastomer like nitrile rubber softening, swelling, hardening, cracking	Free methanol, free water in mixture	[69]

in India. Therefore, the tree is promoted for the production of biodiesel [43]. This oil is sugar rich fruit pulp and can produce ethanol up to 800–1000 l/ha. Simarouba oil can be alternative for diesel run engines within the range of experimentation (B5–B10) [44]. Their high viscosity and poor volatility affect the combustion and emissions considerably in diesel engines. It was observed that apparently the engine ran smoothly with the simarouba oil. The experiment was done by using different blends of biodiesel (B0, B75, B50, B25, B100). For all blends the specific fuel consumption (SFC) curves were in similar trends, while at lower loads the SFC of the blends show clear lower values than B100 and the SFC was lower by 10–15% than the 100% diesel [45].

3.7. Algae

Algal biofuels are poised to become one of the sustainable sources of biofuels that could potentially replace petroleum derived fuels in an environmentally friendly and sustainable world [46]. Algal oil can be processed into biodiesel as easily as oil derived from vegetable and tree borne seeds. The difficulties in efficient biodiesel production from algae lie not in the extraction of the oil, but in finding an algae strain with a significant lipid content and fast growth rate that is not too difficult to harvest. Many other studies have also shown the potential of algal biofuel production in different kinds of wastewater, livestock (dairy) manure wastewater, etc. These are among the fastest-growing plants in the world, and about 50% of their weight is oil. This lipid oil can be used to make biodiesel for cars, trucks, and airplanes. Microalgae have much faster growth-rates than terrestrial crops. The per unit area yield of oil from algae is estimated to be from 20,000 to 80,000 l per acre, per year, which is 7–31 times greater than the next best crop, palm oil [47]. The lipid and fatty acid contents of microalgae vary in accordance with culture conditions. A single acre of algae ponds can produce 15,000 gal of biodiesel [48]. As reported by [15], the city of Bangalore (India) produces nearly 1200 million liters per day (MLD) of sewage that could be processed as indicated above to achieve the triple benefits of algal biofuel production, GHG emission reductions (and CDM attached to it) as well as water purification for reuse.

3.8. Utilization of biodiesel in India

Indian oil corporation (IOC) Ltd., the largest supplier of petroleum fuels has been at the forefront of technology development for production of bio-diesel from various edible and non-edible oils and its application in vehicles. IOC has set up a biodiesel production facility of 60 kg/day at Faridabad. Exhaustive emission testing was carried out on diesel cars and buses of Haryana roadways. Using 10% and 20% blends of bio-diesel in diesel, there was 20% and 25% reduction in CO emission and 5% and 10% reduction in particulate matter, respectively on a diesel car. The bio-diesel was blended by IOC and 20 buses were operated on 5% bio-diesel blend and neat diesel by Rewari terminal of Haryana state. Considerable reduction in smoke was observed in case of buses using 5% bio-diesel blend. The average initial smoke of the buses running on bio-diesel blend was 46.5 Hatridge smoke unit (HSU). The average reduction of smoke was 10.29%, 12.84%, 15.12% and 16% after completion of 1, 2, 3 and 4th month respectively [58]. Mahindra & Mahindra Ltd. has installed a pilot plant utilizing Karanja for biodiesel production in Mumbai. The assessment of engine durability is in progress in collaboration with Tata Motors Ltd., Pune, and field trials using 10% bio-diesel blends are on in multi-utility vehicles in association with Lubrizol India Pvt. Ltd. Mahindra & Mahindra Ltd. is also actively engaged in the development of a continuous process (esterification) for production of bio-diesel [59]. National oilseeds and vegetable oils development (NOVOD) has also initiated test run by blending 10% bio-diesel in collaboration with IIT, Delhi, in automobile vehicles.

Indian railways in association with IOC has running one Shatabadi Express (Delhi to Amritsar), two passenger locomotives (Thanjavur to Nagore section), six trains of diesel multiple units (Tiruchirapalli to Lalgudi, Dindigul and Karur sections) with a 5% blend of bio-fuel sourced from its in-house esterification plants. Field trials of 10% bio-diesel blend were also done on Lucknow–Allahabad Jan Shatabdi Express [59]. Gujarat is the first State in India to run commercial buses using biodiesel fuel using a B5 (5% biodiesel) blend. CSIR and Daimler Chrysler have also jointly undertaken a successful 5000 km trial run of Mercedes cars using bio-diesel as fuel.

3.9. Constraints and problems encountered in the adoption of biodiesel

Research on alternative engine fuels is being conducted all over the world. The plant oils have higher viscosity, lower volatility, the reactivity of unsaturated hydrocarbon chains, and higher percentage of carbon residue [57,60]. Due to these characteristics the possible difficulties were identified in Table 5 viz. carbon deposits on piston, sticking piston rings, valves, engine head and injector tips [61,62], filter plugging, injector coking, nozzle blocking [63,64], failure of engine lubricating oil [61,64], cold weather starting [50,65,66], heavy gum and wax formation, deposition on piston rings, injector and cylinder wall [67], corrosion of high pressure injecting pump, injector nozzles, supply or feed pumps, high pressure pipes [67], Elastomer like nitrile rubber softening, swelling, hardening, cracking, etc. [68]. Most of the problems can be overcome by (i) cracking of the plant oils, (ii) blending of the plant oils with appropriate additives like alcohol, (iii) heating of the plant oils before injecting into the combustion chamber and (iv) chemically transforming the plant oils to convert them into esters (i.e. biodiesels) by alcohol. Among these methods, transesterification is considered to be the best techno-economical alternative. Catalytic cracking of plant oils requires reaction temperature of the order of 350°C. It is expensive and has not been found practical. Blending of oils with alcohol lowers the cetane rating of the fuel to unacceptable levels requiring the use of cetane.

3.10. Suggestions and recommendations

(1) Bio-fuel research should be extended in collaboration with R&D Laboratories, academic institutions and automobile industry to make it a “complete fuel” for the fleet running in the country in a time bound manner.
(2) The economics of biodiesel fuels compared to traditional petroleum resources are marginal; public policy needs to be revised to encourage development.
(3) The cost of biodiesel can be reduced if non-edible oils and used frying oils would be used instead of edible oils.
(4) State and federal governments have made strides in that direction but much more will be required if plant oils are to achieve their potential.
(5) A considerable research effort is needed to increase knowledge about TBO-based biodiesel.

4. Conclusion

Biodiesel has potential as an alternative energy source. Biodiesel operates in compression ignition (diesel) engine, which essentially requires very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. Engine performance was influenced by basic differences between diesel fuel and plant oils such as heating values, viscosity, density and molecular oxygen content. The production of bio-diesel will

provide new horizons to the small and middle scale industries in India. It could provide a direction to India's search for a cost effective alternative fuel in the volatile world market faced with fast-depleting reserves of non-renewable petroleum-based fuels.

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